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Water Quality Interpretive Report No.2

THE CHURCHILL DIVERSION: WATER QUALITY CHANGES IN THE
LOWER CHURCHILL AND BURNTWOOD RIVERS. 1979.

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(Résumé en français)

Canada

**INLAND WATERS DIRECTORATE,
WESTERN AND NORTHERN REGION,
WATER QUALITY BRANCH,
REGINA, SASKATCHEWAN, 1979.**

Cover photograph—

Missi Falls Control Structure,
Churchill River, Manitoba

Courtesy of A. Dalton,
Freshwater Institute,
Department of Fisheries.



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Canada

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et Environnement
Canada

The Churchill Diversion: Water Quality Changes in the Lower Churchill and Burntwood Rivers

R.A. Guilbault, W.D. Gummer and V.T. Chacko

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**INLAND WATERS DIRECTORATE,
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The Chemical Oxygen Demand
Quality Changes in the Lower
Champlain and St. Lawrence Rivers

Water Quality Research Institute
Technical Report No. 10
1979

It is published by the Government of Canada
as part of the Water Quality Research Institute
Technical Report Series

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Cat. No. En 37-53/1979

ISBN 0-662-10447-1

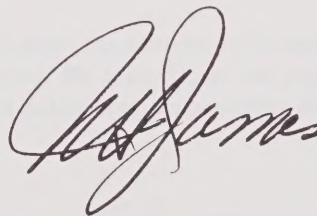
Foreword

Canada is a land richly endowed with fresh water contained in a myriad of sparkling streams and lakes as well as large navigable rivers. It is becoming clear, however, that our water resources are not limitless and that some areas are even now in danger of running short of useable water. Along with a growing awareness that our water resources are limited in certain areas of Canada, concerns for the *quality* of the water throughout Canada are rapidly developing.

Most water uses, be they recreational, agricultural, industrial, or domestic, have very specific requirements for the quality of the water resource. In many instances, the water quality dictates the limitations on the use of a water resource. Therefore, the quality of a water resource can have profound implications on the social and economic development of an area.

Fisheries and Environment Canada has monitored the quality of many of Canada's major surface waters for a number of years. The National Monitoring Program carried on by the Water Quality Branch of the department has varied over the years but has gradually expanded to include approximately one thousand sampling sites, which reflect national, regional, and local water quality concerns. The data are stored on NAQUADAT, the data processing system of the Branch, and are periodically published in summary form in the Water Quality Data series. Although these summaries have proven valuable as reference data sources, it has been realized that these reports can only be fully utilized by persons familiar with the interpretation of water quality data. In order to involve a wider audience in the appreciation of water quality data, this new series, Water Quality Interpretive Reports, has been produced. This report and future ones will parallel the Water Quality Data reports. It is anticipated that this type of report will extend the basic understanding of water quality by utilizing the existing historical water quality data which have been collected by both federal and provincial agencies and entered onto NAQUADAT. These reports will emphasize pertinent water quality information through the use of graphical, tabular, and concise textual presentations.

Individual reports will aim at interpreting regional water quality data for a broad spectrum of uses. It is hoped that these reports will be informative and useful to the public and resource planners.

A handwritten signature in black ink, appearing to read 'N.H. James', is positioned above the printed name and title.

N.H. James
Director General
Inland Waters Directorate

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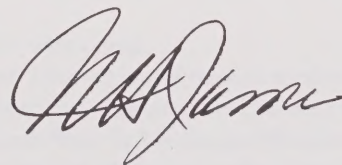
Avant-propos

Le Canada est un pays pourvu de vastes réserves d'eau douce emmagasinées dans une myriade de rivières et lacs miroitants ainsi que grands cours d'eau navigables. Il devient toutefois évident qu'il existe une limite à nos ressources en eau et que certains endroits au pays sont menacés, à l'instant même, par une pénurie d'eau propre. En même temps que s'effectue cette prise de conscience accrue en ce qui concerne la disponibilité des ressources en eau dans des régions données du pays, l'intérêt suscité par la *qualité* des eaux augmente considérablement à travers le Canada.

La plupart des utilisations de l'eau, à savoir récréatives, agricoles, industrielles ou domestiques, ont des normes bien définies en matière de qualité des ressources en eau. Dans bien des cas, la qualité des eaux gouverne les exigences des utilisations possibles des ressources en eau. En fait, la qualité de ses ressources en eau peut avoir des significations profondes sur le développement économique et social d'une région.

Le ministère des Pêches et de l'Environnement du Canada surveille, depuis maintes années, la qualité de plusieurs nappes d'eau de surface importantes au pays. Le programme national de surveillance mis en oeuvre par la Direction de la qualité des eaux du Ministère, a varié en importance au cours des années et s'est graduellement étendu à environ mille stations d'échantillonnage qui reflètent toutes des intérêts nationaux, régionaux et locaux en matière de qualité des eaux. Les données sont emmagasinées dans la banque NAQUADAT, système d'automatisation des données de la Direction, et sont publiées à intervalle régulier sous forme d'extraits dans la série des *Données sur la qualité des eaux*. Quoiqu'utiles en tant que sources de données de base, les extraits semblent principalement destinés aux utilisateurs connaissant les modes d'interprétation des données sur la qualité des eaux. C'est pour encourager la dissémination des données sur la qualité des eaux et améliorer la compréhension d'un public bien informé, que la présente collection intitulée *Water Quality Interpretive Reports* est publiée. Le présent rapport ainsi que les autres qui paraîtront égaleront les rapports de la série des *Données sur la qualité des eaux*. Un rapport de ce genre tente de faire mieux connaître les divers éléments de la qualité des eaux en ayant recours aux données historiques actuelles recueillies à la fois par des organismes fédéraux et provinciaux et enregistrées dans la banque NAQUADAT. Les nouveaux rapports vont mettre en relief l'information qui a rapport à la qualité des eaux en s'appuyant sur des graphiques, des tableaux et un texte clair et concis.

Chaque rapport constituera une interprétation des données sur la qualité des eaux régionales en fonction d'une gamme d'utilisations possibles. De cette façon, les rapports seront du genre didactique et pourront être utilisés par le grand public et les responsables de la gestion des ressources en eau.



N.H. James
Directeur général
Direction générale des eaux intérieures

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Abstract

In June of 1976, Manitoba Hydro commenced operation of the Churchill River diversion, which is part of the Churchill-Nelson Hydroelectric Development Scheme.

A statistical analysis of data obtained from a water quality monitoring network maintained in northern Manitoba by the Water Quality Branch indicates changes in the quality of both the lower Churchill and Burntwood Rivers. On the lower Churchill there is evidence of increases in turbidity, colour, total inorganic carbon, total phosphorus, hardness, calcium and aluminum. On the Burntwood River there is evidence of a decrease in calcium concentration and increases in total phosphorus, potassium and aluminum concentrations. A large number of parameters showed a change in their variability.

The magnitude and cause of the water quality changes cannot be quantified precisely, since the data base used was not collected with this purpose in mind.

Many of the results of this study are in agreement with the general predictions made in 1975 by the Lake Winnipeg, Churchill and Nelson Rivers Study Board.

Résumé

En juin de l'année 1976, l'Hydro-Manitoba a commencé à exploiter la dérivation de la rivière Churchill qui s'intègre au projet d'aménagement du potentiel hydroélectrique du système Churchill-Nelson.

Une analyse statistique des données recueillies par un réseau de contrôle de la qualité des eaux, maintenu dans le nord du Manitoba par la Direction de la qualité des eaux, révèle des modifications dans la qualité des eaux de la rivière Churchill inférieure, aussi bien que de celles de la rivière Burntwood. Sur la rivière Churchill inférieure, il y a preuve d'augmentation de la turbidité, de la couleur, de la dureté des eaux, et des concentrations d'aluminium, de calcium, de phosphore total et de carbone inorganique total. Sur la Burntwood, il y a preuve d'une diminution de la concentration de calcium et d'une augmentation de celles de phosphore total, de potassium et d'aluminium. Un grand nombre de paramètres ont démontré des changements dans leur variabilités.

Il est impossible de déterminer précisément l'ampleur ou les causes de ces modifications dans la qualité des eaux puisque la cueillette des données n'a pas été accomplie dans ce but.

La majorité des résultats de cette étude supporte les prédictions générales faites en 1975 par la Commission d'étude du lac Winnipeg, de la rivière Churchill et du fleuve Nelson.

List of Symbols

p	period of collection; $p=1$ (pre-diversion) $p=2$ (post-diversion)
X_{pi}	i th observation made in period p
N_p	number of observations made in period p
$\bar{X}_p$	mean of observations made in period p
S_p	standard deviation of observations made in period p
S_μ	larger standard deviation of the two periods
S_ν	other standard deviation of the two periods
σ_p	population standard deviation of period p
μ_p	population mean of period p
$F_{a,\mu,\nu}$	F statistic with μ/ν degrees of freedom and probability $\alpha=0.05$
$t_{a,df}$	t statistic with df degrees of freedom and two-tailed probability $\alpha=0.05$
H_0	null hypothesis
H_a	alternative hypothesis

The Churchill Diversion: Water Quality Changes in the Lower Churchill and Burntwood Rivers

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INTRODUCTION

Background

In 1966, the government of Manitoba decided that the province's electrical needs could be met by hydroelectric development in northern Manitoba. The Churchill and Nelson Rivers, in particular, were thought capable of supporting the hydroelectric demand of the province for some time to come. Manitoba Hydro, a crown corporation, began exploiting the hydroelectric potential of the Nelson River by constructing the Kelsey and then the Kettle generating stations in the 1960's. Late in that decade, when plans were being formulated for further development, it was decided that the parallel development of both rivers would be inefficient. Instead, the Corporation's current efforts have been directed toward increasing the hydroelectric potential of the Nelson River by regulating Lake Winnipeg, the source of the Nelson River, and by diverting water from the Churchill River Basin into the Nelson River Basin (Fig. 1).

This report deals with the Churchill River diversion only. The Churchill River diversion scheme involves routing water from Southern Indian Lake, which is essentially a broadening of the Churchill River, through a man-made channel into the Rat River (Fig. 2). The diverted waters are carried by the Rat River into the Burntwood River, which in turn drains into Split Lake, a broadening of the Nelson River. In order to provide a gravity flow across the basin divide through the man-made channel, the level of Southern Indian Lake had to be raised approximately 4 metres. To accomplish this the Missi Falls control structure was built at the outlet of Southern Indian Lake.

In addition, a dam was constructed below Notigi Lake on the Rat River. Its primary function is to store snowmelt to equalize the seasonal discharge. It will also be brought on-line in the 1990's as a 90-megawatt generating station(1).

When construction began in the early 1970's, citizens' groups raised questions about the benefits compared with the social, economic and environmental costs of the scheme.

In response to these questions the governments of Manitoba and Canada appointed the Lake Winnipeg, Churchill and Nelson Rivers Study Board. The Board's objective was:

"to investigate and report on the effects of the works that will regulate Lake Winnipeg, divert flows from the Churchill River, and develop the hydroelectric potential of the Burntwood River on other water and related resource uses; and, to recommend to the federal and provincial governments, measures for enhancing the overall benefits and for mitigating undesirable effects of the hydroelectric projects."(2)

The Board predicted that the diversion would increase the concentration of suspended solids fourfold as well as increasing nutrient concentrations in the Burntwood River as a result of the flooding of organic soils and erosion of the shoreline. The increased discharge would lead to an increased load of both suspended and dissolved material. On the lower Churchill increases were expected in total dissolved solids, dissolved inorganic carbon, calcium, magnesium, turbidity, colour and hardness.

Manitoba Hydro's licence allows it to divert up to 850 cubic metres per second (m^3/s) to the Nelson River. The Board estimated that the *mean* diverted discharge would be $762 \text{ m}^3/\text{s}$ (Table 1).

Table 1. Estimated Discharge for the Churchill River Diversion.

	Mean discharge (m^3/s)	
	Pre-diversion	Post-diversion
Churchill River at outlet of Southern Indian Lake (Missi Falls)	1010	220
Burntwood River at Thompson	99	895
Diversion channel	0	762

When the Missi Falls control structure started operation in June 1976 the discharge (3, 4, 5, 6, 7) below Fidler



Figure 1. Churchill River diversion: index map.

Lake dropped well beneath the long-term monthly means (Fig. 3). However, the discharge in the latter part of 1976 and during 1977 was above the long-term monthly means on the Churchill River (Fig. 4). Therefore, by November 1976, the discharge in the lower Churchill River had returned to normal instead of remaining at the lower than normal levels expected. On the Burntwood River the discharge remained near normal until the fall. From September 1976 the discharge shows a fairly steady increase to sevenfold or more of the long-term monthly means.

Study Methods

This report documents an investigation which uses available data to determine the magnitude and causes of water quality changes in the rivers involved in the Churchill River diversion.

The Water Quality Branch, with the cooperation of the Water Survey of Canada, maintained a network of monitoring sites in northern Manitoba during the period 1961-1977. Seven sites were located in the vicinity of the

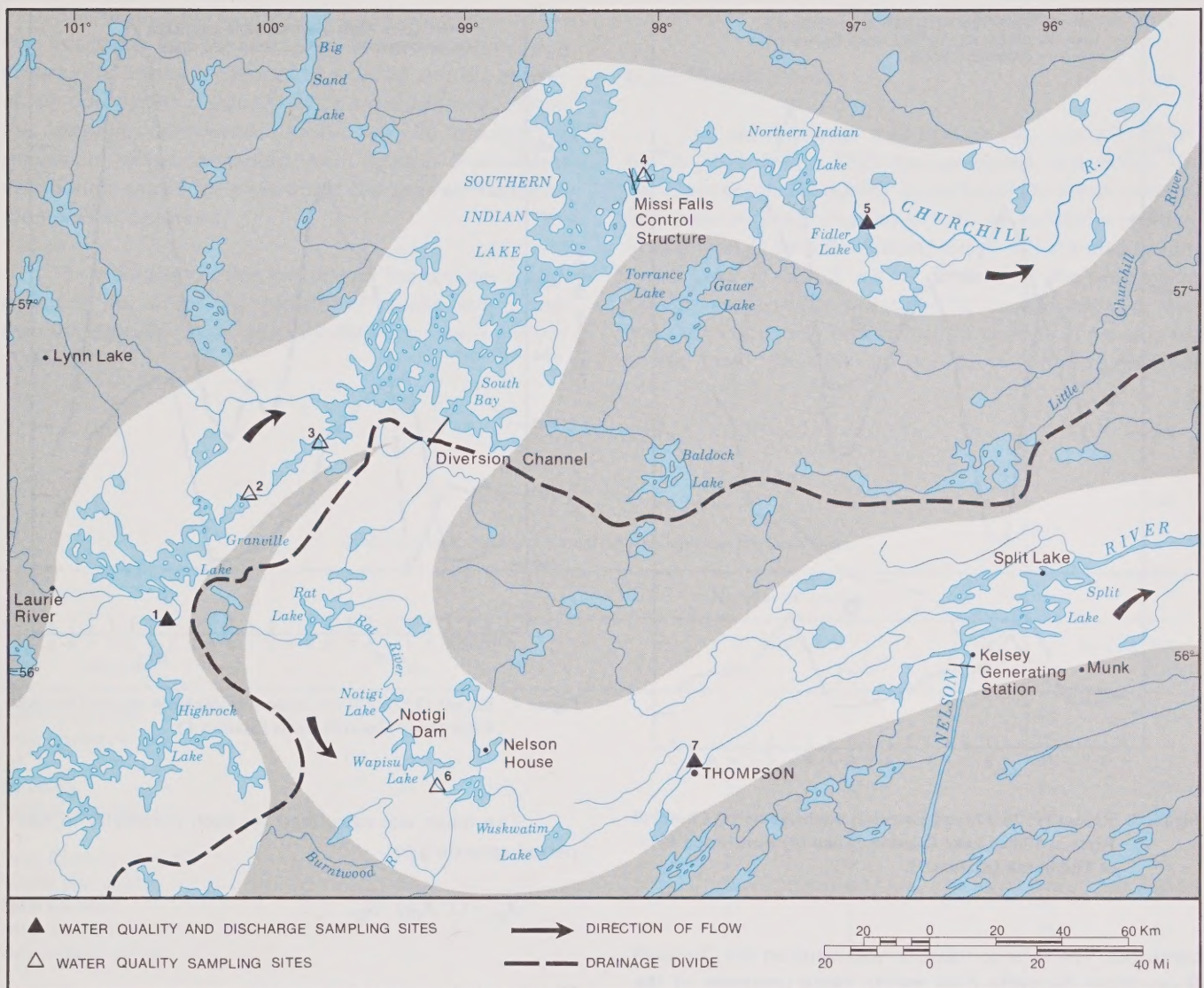


Figure 2. Churchill River diversion: relevant water quality stations.

diversion, five on the Churchill River and one each on the Rat and Burntwood Rivers (Fig. 2). Of these only three—the Churchill River above Granville Falls (Station 1 on Fig. 2) and below Fidler Lake (Station 5) and the Burntwood River near Thompson (Station 7)—have a sufficient quantity of data for statistical analysis. Although this network was established to obtain a general overview of water quality in the area rather than determine trends, the data can be used for determining changes in the area of the Churchill River diversion.

There are drawbacks in using these data for an evaluation of the effects of the diversion on water quality: (i) the sites are not ideally situated for the isolation of the possible diversion effects from other influences, and (ii) the

frequency of sample collection is not constant nor very frequent. In spite of these drawbacks, the data from the monitoring network were examined to determine whether any changes in water quality in the lower Churchill and Burntwood Rivers could be detected which might be attributable to the operation of the Churchill River diversion.

Statistical Methods

In order to determine whether the diversion has affected the quality of the lower Churchill and Burntwood Rivers, the quality of these two rivers before and after the commencement of operation of the diversion must be

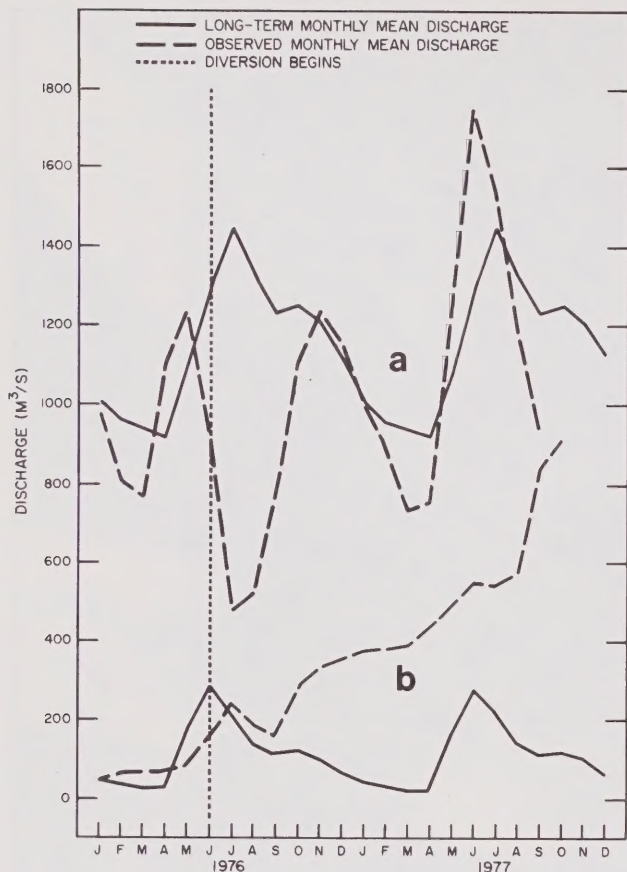


Figure 3. Recent (1976-77) and historical discharge on (a) Churchill River at Fidler Lake (Station 5) and (b) Burntwood River at Thompson (Station 7).

compared. The same comparison was made on the Churchill River above Granville Falls which, being upstream of the diversion, was used as a control.

Statistically, two comparisons are required for our purposes: the comparison of the general levels of the parameter as represented by the mean and the comparison of the variability of the measurements as represented by the standard deviation. The equality of the standard deviations was tested using the "F" statistic, and the approximate confidence interval about the difference in means was calculated using the "t" statistic.

It was assumed that each period (before and after diversion) could be represented by a single mean and standard deviation. The estimates of these two quantities might be poor as a result of the infrequent sample collection. The confidence interval, being proportional to the standard deviation, is large for parameters with strong seasonal variability. This reduces the resolvability of true differences with this method.

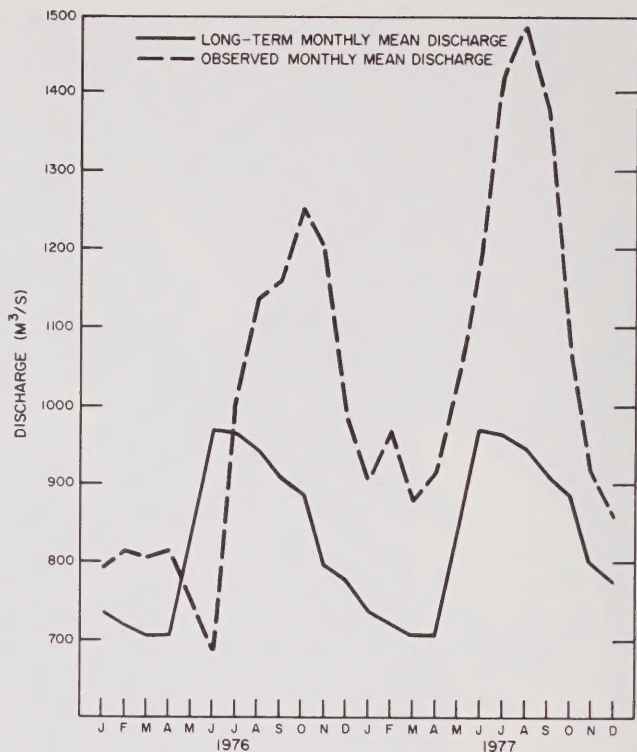


Figure 4. Recent (1976-77) and historical discharge on the Churchill River above Granville Falls (Station 1).

The mean was calculated for each parameter in each period according to:

$$\bar{X}_p = (\sum_i X_{pi}) / N_p \quad (1)$$

The standard deviation is given by:

$$S_p = [(\sum_i (X_{pi} - \bar{X}_p)^2) / (N_p - 1)]^{1/2} \quad (2)$$

For each parameter at each site, the variances of the two periods were tested for equality using:

$$\begin{aligned} F\{a, \mu, v\} > (S_\mu^2 / S_v^2) &\rightarrow H_0: \sigma_1^2 = \sigma_2^2 \\ F\{a, \mu, v\} < (S_\mu^2 / S_v^2) &\rightarrow H_a: \sigma_1^2 \neq \sigma_2^2 \end{aligned} \quad (3)$$

and the difference in means was tested using:

$$\begin{aligned} t\{a, df\} > (\bar{X}_2 - \bar{X}_1) / (\sum_p S_p^2 / N_p)^{1/2} &\rightarrow H_0: \mu_1 = \mu_2 \\ t\{a, df\} < (\bar{X}_2 - \bar{X}_1) / (\sum_p S_p^2 / N_p)^{1/2} &\rightarrow H_a: \mu_1 \neq \mu_2 \end{aligned} \quad (4)$$

The degrees of freedom (df) is then the smaller of the two quantities ($N_1 - 1$) and ($N_2 - 1$). It is expected that between the choice of degrees of freedom and the absence of any assumption of equality of period standard deviations, the resulting confidence interval will be conservative enough to offset deviations from normal independent distribution within the periods and the poor estimation of the standard deviations.

Only parameters that had at least five samples in each period or for which the majority of results were greater than the detection limit were included in the above analysis (Table 2).

RESULTS AND DISCUSSION

Lower Churchill River

The above-average discharge in the Churchill River late in 1976 and in 1977 has confounded the effects of the diversion on the quality of the lower Churchill. Despite this, there are fewer changes in both the variability and the general level of parameters above Granville Falls than below Fidler Lake (Tables 3 and 4). Because of the geographic distance and possible environmental changes between the two sites, it can only be said that the changes in the quality of the lower Churchill are due to an influence located

Table 2. Water Quality Parameters Available on the Data Base.

Parameter	Number of analyses					
	Station 1		Station 5		Station 7	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
Colour, apparent	25	7	31	6	94	12
Temperature, <i>in situ</i>	—	—	—	—	66	8
pH	25	7	31	6	95	12
Turbidity	25	7	31	6	94	12
Residue, non-filterable	—	—	—	—	28	10
Total Kjeldahl nitrogen	18	7	19	6	41	12
Nitrate plus nitrite	23	7	29	6	90	12
Total nitrogen	16	7	17	6	40	12
Total inorganic carbon	24	7	25	6	45	12
Total organic carbon	24	7	25	6	47	12
Total phosphorus	20	7	23	6	44	12
Specific conductance	25	7	31	6	95	12
Alkalinity, total	25	7	31	6	95	12
Hardness, total	22	7	30	6	88	12
Stability Index — Ryznar	24	6	—	—	94	11
Calcium, dissolved	25	7	31	6	95	12
Magnesium, dissolved	22	7	31	6	88	12
Sodium, dissolved	25	7	31	6	94	12
Potassium, dissolved	25	7	31	6	95	12
Chloride, dissolved	25	7	31	6	94	12
Fluoride, dissolved	24	7	—	—	64	12
Sulphate, dissolved	19	7	31	6	76	12
Silica, reactive	25	7	31	6	91	12
Saturation Index-Langelier	24	6	—	—	66	11
Aluminum, extractable	9	7	11	6	5	13
Copper, extractable	14	7	13	5	16	13
Iron, extractable	13	7	14	6	17	13
Manganese, extractable	14	7	14	6	17	13
Nickel, extractable	—	—	—	—	14	13
Zinc, extractable	14	7	13	5	15	13

somewhere between the two sites. Regardless of the cause of changes in water quality, the pattern of changes in concentrations is generally that expected by the Board. The turbidity increased 370 per cent, colour 107 per cent, calcium 43 per cent, hardness 31 per cent, and total inorganic carbon 28 per cent. Contrary to the Board's predictions, there was no change in magnesium concentrations and total dissolved solids as indicated by specific conductance measurements. Increases in total phosphorus and aluminum were found but had not been predicted by the Board.

These last results will be discussed in relation to Burntwood River.

A number of parameters below Fidler Lake show a change in variability, most showing an increase by a factor of 1.9 to 3.2. Aluminum variability shows an order of magnitude increase. The variability of four parameters appears to have decreased. The behaviour, in terms of variability of the data, is difficult to rationalize, since there is no pattern to the changes.

Table 3. Churchill River Diversion: Changes in Water Quality Means.

Parameter (units)	STATISTICS								
	P*	N _p	Maximum	Minimum	$\bar{X}_p$	S _p	$\bar{X}_2 - \bar{X}_1$	$\Delta^\dagger$	S _δ [‡]
a) CHURCHILL RIVER below Fidler Lake (Station 5)									
Turbidity (JTU)	1	25	4.8	0.5	2.1	1.2			
	2	7	15.0	4.1	10.0	3.8	+7.9	+376	1.5
Colour, apparent (Relative units)	1	25	20.0	5.0	9.9	5.0			
	2	7	30.0	10.0	18.6	6.9	+9.6	+107	2.8
Total inorganic carbon (mg/L as C)	1	24	12.0	5.0	8.8	2.0			
	2	7	14.0	10.0	11.3	2.0	+2.5	+28	0.9
Phosphorus, total (mg/L as P)	1	20	0.003	0.010	0.010	0.004			
	2	7	0.032	0.010	0.020	0.010	+0.010	+100	0.004
Hardness, total (mg/L as CaCO ₃)	1	22	63.0	36.0	44.3	5.6			
	2	7	65.5	53.2	58.0	5.4	+13.7	+31	2.4
Calcium, dissolved (mg/L as Ca)	1	25	17.3	10.0	12.7	1.8			
	2	7	24.7	14.6	18.1	3.4	+5.4	+43	1.3
Aluminum, extractable (mg/L as Al)	1	9	0.12	0.06	0.10	0.02			
	2	7	0.68	0.1	0.32	0.21	+0.22	+220	0.08
b) BURNTWOOD RIVER near Thompson, (Station 7)									
Phosphorus, total (mg/L as P)	1	44	0.075	0.05	0.030	0.015			
	2	12	0.11	0.031	0.060	0.020	+0.030	+100	0.006
Calcium, dissolved (mg/L as Ca)	1	95	26.9	12.3	21.3	2.7			
	2	12	21.9	17.9	19.9	1.3	-1.4	-7	0.5
Potassium, dissolved (mg/L as K)	1	95	1.6	0.4	1.0	0.8			
	2	12	2.3	1.0	1.5	0.4	+0.5	+50	0.1
Aluminum, extractable (mg/L as Al)	1	5	0.008	0.02	0.04	0.02			
	2	13	0.94	0.1	0.54	0.25	+0.50	+1250	0.07
c) CHURCHILL RIVER above Granville Falls, (Station 1)									
Turbidity (JTU)	1	31	1.5	8.7	3.9	1.6			
	2	6	3.4	12.0	7.5	3.0	+3.6	+92	1.4

*P = period of record. 1 = pre-diversion; 2 = post-diversion.

† Difference as percentage of $\bar{X}_1$.

‡ S_δ = standard deviation of difference in the means.

Table 4. Churchill River Diversion: Changes in Water Quality Variability

Parameter (Units)	STATISTICS					
	P*	N _p	Maximum	Minimum	S _p	R [†]
a) CHURCHILL RIVER below Fidler Lake (Station 5)						
Turbidity (JTU)	1	25	4.8	0.5	1.2	3.2
	2	7	15.0	4.1	3.8	
pH (pH Units)	1	25	7.9	7.3	0.19	2.7
	2	7	8.2	6.7	0.51	
Total Kjeldahl nitrogen (mg/L as N)	1	18	0.9	0.3	0.14	2.5
	2	7	1.05	< 0.10	0.35	
Total nitrogen (mg/L as N)	1	16	1.10	0.39	0.17	2.2
	2	7	1.13	0.11	0.37	
Nitrate plus nitrite (mg/L as N)	1	23	0.300	< 0.001	0.08	0.4
	2	7	0.083	< 0.01	0.03	
Total phosphorus (mg/L as P)	1	20	0.018	0.003	0.004	2.5
	2	7	0.032	0.001	0.010	
Alkalinity, total (mg/L as CaCO ₃)	1	25	126.0	36	17.6	0.3
	2	7	64.2	49.1	5.7	
Calcium, dissolved (mg/L as Ca)	1	25	17.3	10	1.8	1.9
	2	7	24.7	14.6	3.4	
Magnesium, dissolved (mg/L as Mg)	1	22	5.9	2.0	0.9	1.9
	2	7	4.9	0.9	1.7	
Sulphate, dissolved (mg/L as SO ₄)	1	19	5.0	1.0	1.2	2.3
	2	7	10.0	2.3	2.7	
Saturation Index (pH Units)	1	24	-0.5	-1.8	0.3	2.0
	2	6	-0.1	-1.7	0.6	
Aluminum, extractable (mg/L as Al)	1	9	0.12	< 0.06	0.02	10.5
	2	7	0.68	< 0.1	0.21	
Copper, extractable (mg/L as Cu)	1	14	0.31	< 0.001	0.085	0.05
	2	7	0.011	< 0.001	0.004	
Iron, extractable (mg/L as Fe)	1	13	0.24	< 0.04	0.06	3.0
	2	7	0.58	0.06	0.18	
Manganese, extractable (mg/L as Mn)	1	14	0.026	< 0.01	0.005	2.4
	2	7	0.030	< 0.001	0.012	
Zinc, extractable (mg/L as Zn)	1	14	0.11	< 0.001	0.033	0.2
	2	7	0.018	0.001	0.006	
b) BURNTWOOD RIVER near Thompson (Station 7)						
Turbidity (JTU)	1	94	200.0	0.04	21.8	0.2
	2	12	28.0	12.0	5.1	
Colour, apparent (Relative units)	1	94	80	5	14	1.6
	2	12	100	10	22	

Table 4 (Cont'd)

Parameter (Units)	STATISTICS					
	P*	N _p	Maximum	Minimum	S _p	R [†]
pH (pH units)	1	95	9.0	7.1	0.28	1.5
	2	12	7.9	6.4	0.43	
Nitrate plus nitrite (mg/L as N)	1	90	2.03	< 0.001	0.24	0.2
	2	12	0.21	< 0.01	0.06	
Total organic carbon (mg/L as C)	1	47	18	10	2	4.0
	2	12	39	7	8	
Specific conductance (μs/cm)	1	95	1.85	25	20	6.0
	2	12	161.00	92.6	119	
Calcium, dissolved (mg/L as Ca)	1	95	26.9	12.3	2.7	0.5
	2	12	21.9	17.9	1.3	
Potassium, dissolved (mg/L as K)	1	95	1.6	0.4	0.8	0.5
	2	12	2.3	1.0	0.4	
Chloride, dissolved (mg/L as Cl)	1	94	12.0	0.5	1.5	0.3
	2	12	2.5	0.9	0.5	
Fluoride, dissolved (mg/L as F)	1	64	0.47	< 0.05	0.08	3.6
	2	12	1.05	< 0.01	0.29	
Sulphate, dissolved (mg/L as SO ₄)	1	76	38.3	1.4	4.1	0.2
	2	12	6.1	2.6	0.9	
Saturation Index (pH Units)	1	66	0.8	-1.3	0.34	1.5
	2	11	-0.4	-2.1	0.52	
Aluminum, extractable (mg/L as Al)	1	5	0.08	0.02	0.02	12.5
	2	13	0.94	< 0.1	0.25	
Copper, extractable (mg/L as Cu)	1	16	0.008	0.002	0.002	3.5
	2	13	0.024	< 0.001	0.007	
Manganese, extractable (mg/L as Mn)	1	17	0.10	< 0.01	0.029	0.4
	2	13	0.05	< 0.01	0.013	
c) CHURCHILL RIVER above Granville Falls, (Station 1)						
Turbidity (JTU)	1	31	8.7	1.5	1.6	1.9
	2	6	12.0	3.4	3.0	
pH (pH units)	1	31	7.9	7.2	0.2	2.0
	2	6	7.9	6.8	0.4	
Chloride, dissolved (mg/L as Cl)	1	31	2.5	< 0.1	0.5	0.4
	2	6	1.3	0.8	0.2	
Sulphate, dissolved (mg/L as SO ₄)	1	31	6.4	1.3	1.2	3.3
	2	6	11.5	2.9	4.0	
Zinc, extractable (mg/L as Zn)	1	13	0.110	< 0.002	0.031	0.2
	2	5	0.014	0.001	0.005	

*P = period of record. 1 = pre-diversion; 2 = post-diversion.

†R = S₂/S₁

Burntwood River

In view of the radical change in flow regime, the changes in quality are a result of the diversion. The identified changes are not what were expected by the Board. There were no significant changes in the concentration of suspended solids, based on turbidity and non-filterable residue analyses, nor were there increases in nitrogen or carbon concentrations. It is believed that the Notigi reservoir is acting as a settling basin for the suspended solids.

Calcium decreased about 7 per cent in the Burntwood River in the post-diversion period. This is consistent with results expected from mixing diversion waters with local drainage. The mean potassium concentration increased from 1.0 to 1.5 mg/L (Table 3) after the diversion and cannot be explained by the addition of Churchill River water to the Burntwood River. Mean potassium concentrations were 1.2 and 1.0 mg/L at stations 1 and 5, respectively, after the diversion. Increases in total phosphorus (100%) and aluminum (1250%) occurred, although no changes in either turbidity or non-filterable residue were evident. Phosphorus and aluminum may be associated with water-soluble organic acids, but there were no changes in organic carbon concentrations. Aluminum and phosphorus both occur in a number of fairly common minerals associated with Precambrian granite (2, 8), which is the bedrock throughout the area. Since the soil is derived from the bedrock, the leaching and erosion of the soil in the area may release these elements to the water column in either a dissolved or a colloidal state.

The ratio of the standard deviations of the pre- and post-diversion periods for the parameters of the Burntwood River, which range between 0.2 and 12.5, are greater than those of the Churchill River. The very large change in the flow regimes of the Rat and Burntwood Rivers, which has resulted in a great deal of land being flooded, may be the cause. The change from terrestrial to aquatic environment often produces marked changes in the associated water quality, but the interaction and results are complex and difficult to predict.

SUMMARY AND CONCLUSIONS

There is evidence that the water quality of the lower Churchill and Burntwood Rivers has changed since June 1976. Mean levels of total phosphorus and aluminum have increased in both rivers. The variability of aluminum has also increased substantially in both rivers. On the lower

Churchill River there were also increases in turbidity (376%), colour (10%), total inorganic carbon (28%), total hardness (31%) and calcium (43%). In addition to aluminum, 11 parameters showed approximately a twofold increase in their variability. However, four parameters—nitrate plus nitrite, total alkalinity, copper and zinc—decreased in variability.

On the Burntwood River potassium concentrations increased 50 per cent, and calcium decreased 7 per cent. Excluding aluminum, seven parameters showed an increase between 1.5 and 6-fold in their variability, while seven parameters showed a decrease.

The limitations of the data base make it difficult to quantify trends in the quality of the lower Churchill and Burntwood Rivers. However, the results of the study tend to agree with the predictions made in 1975 by the Lake Winnipeg, Churchill and Nelson Rivers Study Board.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contribution of the Water Survey of Canada in providing unpublished data. We would also like to thank Dwight Quiring and the Drafting Section, IWD, for their drafting assistance and all the Inland Waters staff members who have reviewed the original manuscript and provided their comments.

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CA1 EP 76079W02

Canada. IWD.

Water Quality Interpretive Report No.2

THE CHURCHILL DIVERSION: WATER QUALITY CHANGES
LOWER CHURCHILL AND BURNWOOD RIVERS, 1979.

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